RETROSPECTIVE

David Thouless (1934–2019)

Quintessential topological condensed matter physicist

By **Marcel den Nijs**

David James Thouless, 2016 Nobel laureate and emeritus professor of Physics at the University of Washington, passed away on 6 April 2019 at age 84. One of the most influential condensed matter physicists of his generation, David identified topology as the unifying thread in his research, which was of crucial importance to the current rapid developments in materials and technology.

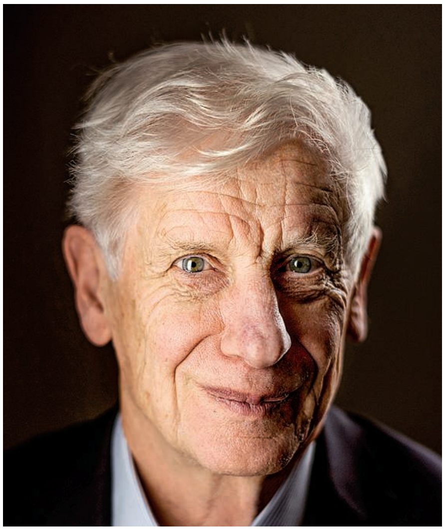
David was born in 1934 in Bearsden, Scotland. His mother taught English, and his father was a psychology professor. After receiving his undergraduate degree in mathematics from the University of Cambridge, David moved to Cornell University in Ithaca, New York, where he met his wife-to-be, Margaret. In 1958, the year David received his Ph.D. in physics under adviser Hans Bethe, he and Margaret married. Their three children are scientists and educators like their parents and grandparents.

After postdoctoral research at the University of California, Berkeley, David returned to England to direct the physics department of Churchill College in Cambridge. He soon became a physics professor at the University of Birmingham. It was there that, in 1973, he and physicist Michael Kosterlitz revolutionized our understanding of two-dimensional (2D) phase transitions with their discovery of the unbinding transition of vortex-antivortex pairs. Whirlpools in water or the circulation trails in the wake of airplanes are examples of vortices. These phenomena also appear in quantum liquids, but with one crucial difference: Their circulation is quantized. The gradient of the velocity is proportional to the phase of the order parameter so that by topology, the closed contour integral yields a multiple of 2π. The Kosterlitz-Thouless (KT) breakthrough showed that this quantum leads to a sharp phase transition even in two dimensions. KT transitions proved to be common in 2D critical phenomena and were also the backbone in the Coulomb gas methods by which I and others derived the exact values of the critical exponents of virtually all 2D universality classes around 1980.

Department of Physics, University of Washington, Seattle, WA 98195, USA. Email: london@uw.edu

Bishop and Reppy confirmed the KT transition experimentally in superfluid helium in 1978. They gifted David with a framed copy of their original data during his 65th birthday symposium. It took center stage in his office, next to his Wolf Prize certificate and is now in the Nobel Museum collection. David, who often pointed out that theory tends to lag behind experimental discoveries, was proud of this counterexample.

After spending a year at Yale University, David and Margaret moved to Seattle in 1980, where both were offered faculty positions at the University of Washington. I arrived later that same year as a postdoc. We joined an exceptional condensed matter environment where theorists and experimentalists interacted well. Peter Nightingale, one of the pioneers of finite-size scaling methods, and Mahito Kohmoto were the other theory postdocs.



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Upon my arrival, I found Mahito and David working on the quantum Hall effect. In 1980, von Klitzing, Dorda, and Pepper had shocked the world with their discovery of perfect steps in the Hall conductance in semiconductor interfaces. This quantization is so perfect that it currently defines the unit of the ohm. The value of the quantum e^2/h was obvious; the mystery was why disorder did not destroy it. David approached this puzzle from a transport theory perspective. The Kubo formula should reproduce the quantization but stubbornly refused to show him how. In the venerable tradition of corralling a specific question in a precise toy model, Mahito and David took out the disorder and added instead a periodic potential to the free electron gas, leading to the famous Hofstadter Butterfly band structure.

David was gentle, caring, and friendly, but doing research with him could be a challenge. To paraphrase Michael Kosterlitz, working with David was not for the faint hearted; he was too fast for most mortals to keep up with. As a result, all three Seattle theory postdocs were soon involved in the quantum Hall effect project.

First, Peter and Mahito confirmed quantization in the butterfly gaps numerically and discovered an intricate pattern. Next, David pulled from his magic mathematician hat the precise formulas for that pattern. After drafting our paper, we reflected on the larger picture. David's brilliant setup of the problem had led us to a point at which the next step became obvious. I realized that the Bloch theorem aspects of the model begged us to rewrite the surface integral in the Kubo formula into a closed contour integral along the Brillouin zone edge. As soon as we did, the Hall current turned into a phase factor–type quantum number, more complex but similar to vorticity in superfluids. This proved not only the quantization but also why it was topologically protected.

A *Physical Review Letter* should have only one single message, according to David, but for this, he abandoned that principle. We squeezed the now famous Eq. 5 into the paper. A few weeks later, Barry Simon happily informed David that we had discovered an application of Chern invariants. Today, Eq. 5 is known as the TKNN (Thouless, Kohmoto, Nightingale, den Nijs) invariant and serves as a pre-Berry example of Berry Phase phenomena (1984). This discovery set the stage for the current new era in condensed matter physics that combines 2D quantum materials, such as graphene, with vastly improved experimental technology.

David's deteriorating health made it increasingly difficult for him to communicate, but he clearly enjoyed receiving the Nobel Prize celebrating his lifetime achievements. The day after the Nobel ceremonies, my family and I had lunch with David and Margaret. At one point, Margaret asked our daughter for her age. David immediately gave the correct answer. To him it was obvious. Even then, he could still compute her age precisely because she shares a birth date with his father.

The impact of David Thouless on science will be long lasting. In his honor, the Physics Department of the University of Washington now includes the Thouless Institute for Quantum Matter. ■

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